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J. R. MANZANO - J. G. ROEDERER - O. R. SANTOCHI

Cosmic Ray Intensity Variations during the Magnetic Storm in May 1959

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Cosmic Ray Intensity Variations during the Magnetic Storm in May 1959.

J. R. MANZANO, J. G. ROEDERER and O. R. SANTOCHI
Comisión Nacional de Energía Atómica - Buenos Aires

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Summary. — Cosmic ray intensity during the May 1959 magnetic storm is analysed, using neutron monitor and cubic telescope data from Mina Aguilar, Buenos Aires, Ushuaia and Ellsworth (Antarctica). The primary variation spectrum is estimated according to a method outlined in a recent paper (¹). The intensity behaviour during recovery is analysed in detail. Following results are obtained. The primary variation spectrum, acting until the 18th of May, has an approximate form given by $\delta D/D = \delta k(t)\cdot E^{-0.5}$, valid up to very high energies. Around the 18th, this spectrum changes its shape at low energies (< 2 GeV), in a similar way as it occured during the July 1959 storm recovery. This change may be interpreted as an additional removal of low energy particles, which lasted at least until the end of the month. On May 14, intensity variation is quite peculiar, in spite of being this a quiet day from the solar and geomagnetic point of view. A world-wide decrease occurs, with a superposed, 10 h lasting increase, which is particularly high at Ellsworth (9% in the neutron monitor, 2% for the cubical telescope). It is shown that Ellsworth was located in a 04 impact zone for a simultaneous solar event. On the 24th, a world-wide, small Forbush decrease occurred, associated with a magnetic storm and a decrease in the horizontal component of the magnetic field. This Forbush decrease, which shows a strong longitude dependence, corresponds to a primary variation spectrum which has the same shape as that responsible for the general recovery acting at the time, *i.e.*, after the low energy change on the 18th.

(¹) J. G. ROEDERER, O. R. SANTOCHI, J. C. ANDERSON, J. M. CARDOSO and J. R. MANZANO: *Nuovo Cimento*, **18**, 120 (1960).

1. – Introduction.

The May 1959 Forbush decrease (²) was associated with a sudden magnetic storm commencement which started at 2318 UT on May 11. This storm is presumably linked with the strongest solar flare so far reported in this cycle, which occured on May 10, at 2102 UT (³), lasting for several hours. A strong increase of low energy proton flux at 10 g/cm² atmospheric depth, was reported for the 12th of May (⁴). During the recovery of cosmic ray intensity solar and geomagnetic activity was still high. Particularly on the days 11, 13 and 17, the solar BT 48 region was extremely active. Geomagnetic activity was high on days 15 and 24.

In the present paper, cosmic ray modulation effects during this period will be analysed, and their connection to solar and geomagnetic activity will be discussed.

Records from following stations were used in this analysis: neutron monitor Mina Aguilar (4 000 m o.s.l., 12° S geomagnetic latitude), neutron monitor and cubical telescope Buenos Aires (sea level, 23° S), neutron monitor Ushuaia (sea level, 43° S) and neutron monitor and cubical telescope Ellsworth (*) (sea level, 67° S). Cubical telescope data were corrected for pressure only. For this reason, they will be considered for qualitative arguments only. Hourly, or bihourly percentage variations are shown in Fig. 1. The reference level is given by the mean intensity during quiet days preceding the increase in geomagnetic activity on the 4th of May. Buenos Aires neutron monitor data are not shown: percentage variations coincide within minor fluctuations with those at Mina Aguilar. K_p values and the horizontal component of the earth's magnetic field recorded at Pilar (Argentina), are shown below.

A first inspection of Fig. 1 suggests to divide the whole period into seven subintervals:

1) May 11, 23 UT – May 13, ∼22 UT: big Forbush decrease associated with a SC magnetic storm, which lasted 24 hours. Gradual intensity recovery. Strong solar activity on 11 and 13th.

2) May 13, 22 UT – May 14, 18 UT: sudden decrease of several percent, followed by an increase, detected at all stations, which lasted about 10 hours,

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(²) F. Bachelet, P. Balata, A. M. Conforto, N. Iucci and G. Marini: *Nuovo Cimento*, **13**, 1055 (1959).

(³) *Preliminary reports, High Altitude Observatory* (Boulder, Colo.).

(⁴) E. P. Ney, J. R. Winckler and P. S. Freier: *Phys. Rev. Lett.*, **3**, 183 (1959).

(*) Operated in collaboration with the University of California and the Instituto Antártico Argentino.

and which is very strong for the Ellsworth nucleon intensity. Intensity falls back to a minimum, which by the way is the absolute minimum for the whole May disturbance. No important flare was reported for this day; geomagnetic activity was at lowest level compared to preceding and following days.

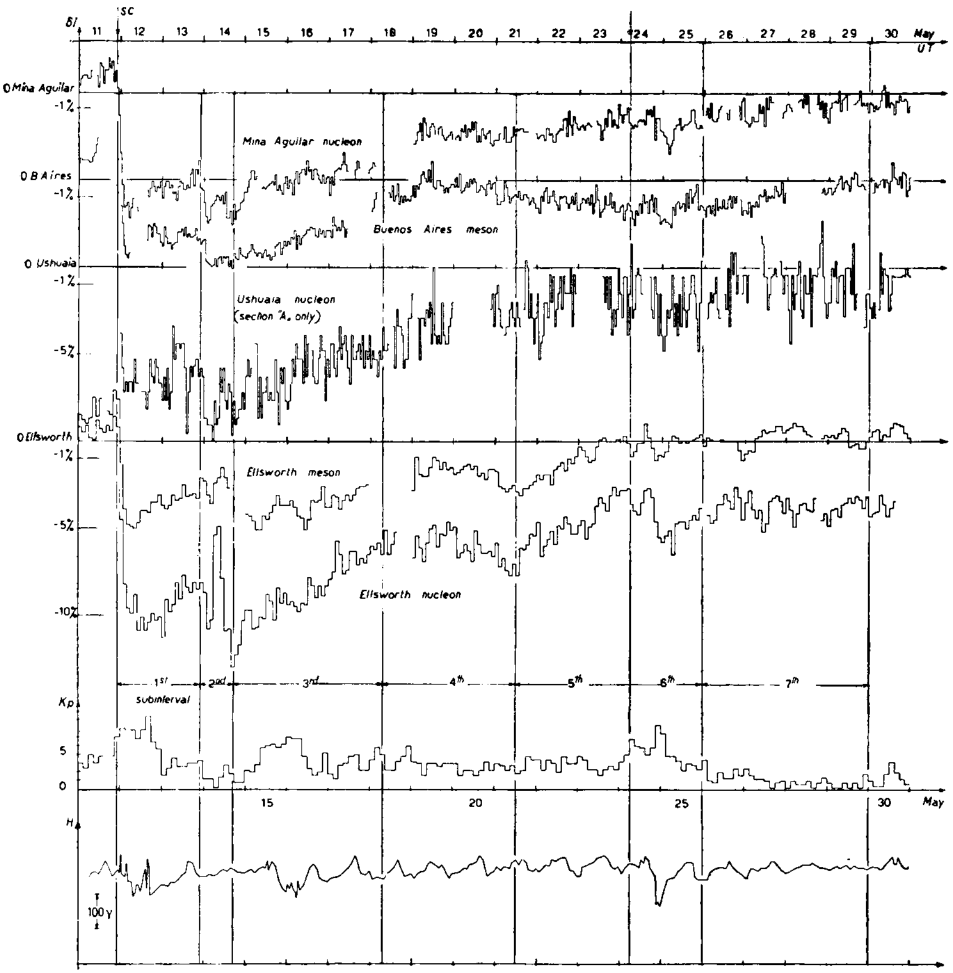

Fig. 1. – Percentage variations of intensity for different detectors. K_p indices and horizontal component of geomagnetic field intensity are shown below. The division of the whole period into seven subintervals according to cosmic ray behaviour is indicated. For further details, see text.

3) May 14, 18 UT – May 18: almost undisturbed recovery at all stations. The magnetic storm on the 15th apparently had no influence on cosmic radiation.

4) May 18 – May 21, ~ 12 UT: general leveling off and/or decrease of intensity. No peculiar geomagnetic events, except constant high activity. Solar activity was high on the 17th, decreasing gradually afterwards.

5) May 21, ~ 12 UT – May 24, 06 UT: undisturbed recovery, except at Buenos Aires N.M. and C.T. No appreciable change in geomagnetic activity; solar activity steadily decreasing.

6) May 24, 00 UT – May 25, 24 UT: small Forbush decrease associated with a magnetic storm of sudden commencement starting 05.40 UT, and a pronounced decrease in horizontal component. Notice the «fine structure» reproduced by all detectors, of two well separated decreases, or maybe one decrease with superposed increase at ~ 1800 UT on the 24th.

7) May 26 – May 30: recovery at low latitudes, and leveling off at high latitudes. Geomagnetic activity decreasing fast. After the 30th geomagnetic activity increases again.

It is a remarkable feature of some of these well defined subintervals of characteristic cosmic ray behaviour, that it is difficult to establish a plausible causal relationship with large solar and terrestrial phenomena so far reported.

2. – The primary variation spectrum.

The first task will be to determine the approximate form of the primary variation spectrum, and to establish whether it changed from interval to interval. We applied the method given in (¹), in order to estimate the parameters of the variation spectrum, expressed in the approximate form

$$\frac{\delta D}{D} = \begin{cases} \delta k(t)\cdot E^{-\gamma} & \text{for } E<\varepsilon_0\,, \\ 0 & \text{for } E>\varepsilon_0\,. \end{cases}$$

Bihourly ΔI vectors ((¹), Section 2) for the pair of neutron monitors Ells-

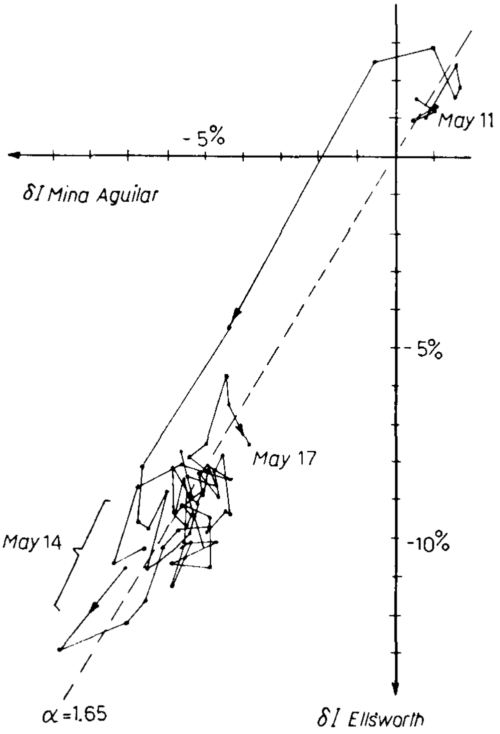

Fig. 2. – Percentage intensity variation diagram for Ellsworth and Mina Aguilar neutron monitors, for the 1st and 3rd subinterval. The increase occuring during the 2nd sub-interval is excluded. The best fit line is shown.

worth-Mina Aguilar and Ushuaia-Mina Aguilar are shown in Fig. 2 and Fig. 3, respectively. From the prestorm increase until the 17th, 24 UT, the best fit is obtained for

$$\alpha_{\text{ELLS-MA}} = 1.65 \pm 0.10\,,$$

$$\alpha_{\text{USH-MA}} = 1.22 \pm 0.12\,.$$

In Fig. 2, we omitted the interval 05 UT to 15 UT of the 14th, during which the steep increase at Ellsworth occurred. Notice that both decreases, that of the 11th and that of the 14th, do not show any appreciable difference in α. This suggests that the primary variation spectrum did not change during the additional decrease in the second subinterval. In other words, both modulation mechanisms were of the same type, having linearly superposed effects on cosmic ray intensity (5).

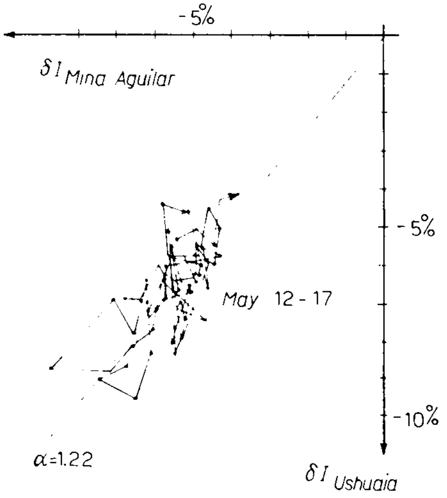

Fig. 3. – Item Fig. 2, for Ushuaia *vs.* Mina Aguilar. Data of the 11th of May are not available for Ushuaia.

In order to have a further intermediate point in the southern hemisphere, we used data from Mt. Wellington (*), which has a geomagnetic cut-off of 2 GeV total energy, according to (6). We obtain

$$\alpha_{\text{MTWELL-MA}} = 1.52 \pm 0.09$$

Using the theoretical curves given in (1), completed with those for Ushuaia and Mt. Wellington, we get a best fit for a spectrum of the form

$$\gamma = 0.48 \pm 0.05\,; \qquad \varepsilon_0 \simeq \infty\,.$$

In Fig. 4, theoretical curves for α are represented as a function of γ, assuming $\varepsilon_0 = \infty$. The experimental α values with their errors are marked on the curves.

(5) J. G. Roederer, O. R. Santochi, J. C. Anderson, J. M. Cardoso and J. R. Manzano: *Nuovo Cimento*, **18**, 131 (1960).

(*) We thank the Cosmic Ray Group of the University of Tasmania for sending their data.

(6) J. J. Quenby and W. R. Webber: *Phil. Mag.*, **4**, 90 (1959).

In order to eliminate the intense daily variation, we smoothed the percentage variations taking 24 hour moving averages after the 15th, 00 UT. We excluded from this procedure the whole 6-th subinterval, in which the

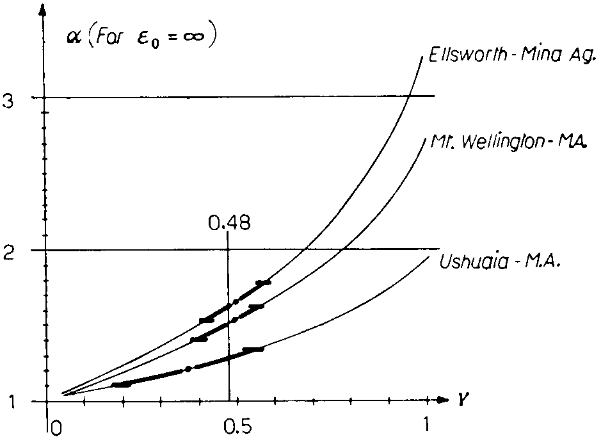

Fig. 4. – Theoretical curves for the cofficient α, corresponding to a variation spectrum of type $\delta k(t) E^{-\gamma}$ extending to highest energies ($\varepsilon_0 = \infty$). Experimental values are indicated.

small Forbush decrease took place. Fig. 5 shows the δI correlation diagram for Ellsworth-Mina Aguilar using average intensity. A clear departure from the initial $\alpha = 1.65$ line is seen after the 18th of May, *i.e.*, after the 3-rd subinterval. According to the discussion given in Section 2 of (¹), we conclude that a change in the primary variation spectrum occurred around the 18th, and lasted for the rest of the period. Fig. 6 shows the corresponding diagram for the pair of stations Ushuaía-Mina Aguilar. No appreciable change is seen after the 18th. In order to assure that this change was not a local effect, extending to high energies at Ellsworth, we correlated the intensity variation of both detectors, N.M. and C.T., at Ellsworth. The

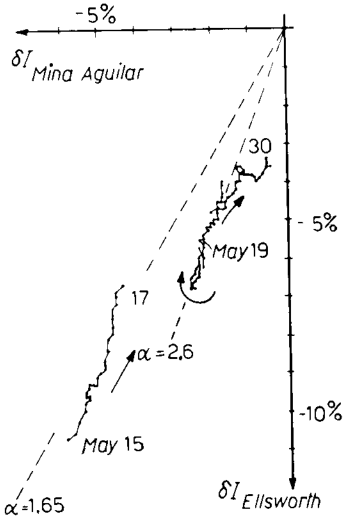

Fig. 5. Percentage variation diagram for smoothed intensity, for the pair of neutron monitors Ellsworth - Mina Aguilar, corresponding to the days after the second sub-interval. Data from Mina Aguilar for the 18th of May are not available. The change in the slope occuring after the 3-rd subinterval is indicated (see text).

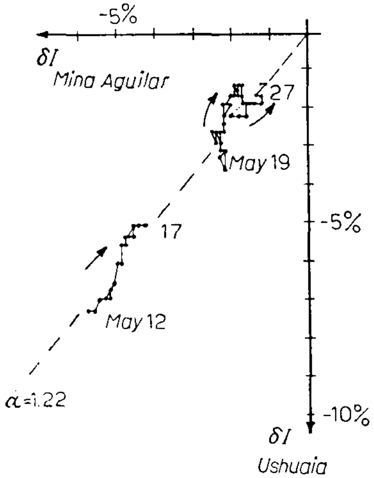

Fig. 6. – Item Fig. 5, for the pair Ushuaia - Mina Aguilar. No appreciable change after the 18th is revealed.

curve of Fig. 7 is obtained. The departure starting on the 18th clearly indicates a change in the low energy part of the *local* primary variation spectrum.

No special solar or terrestrial event was reported for the 18th. The most one may assume, is a connection with the strong solar activity on the 17th, which in some way caused a long lasting depression in the flux of low energy particles. We point out that during the recovery after the third July storm, a similar, but slower, change in the primary variation spectrum occured after the 19th-20th of July. In summary, in both storms, May and July, low energy particle intensity recovered slower than the high energy flux. Notice that the magnetic storm of the 15th of May had no effect on cosmic ray intensity.

Finally, coming back to Fig. 2, we realize that all ΔI vectors corresponding to the sudden decrease on the 11th, lie well above the $\alpha = 1.65$ line. This effect, which is also found for the first July storm (see Fig. 6 of (¹)), is due to a shift in time of cosmic ray storm commencement between Ellsworth and Mina Aguilar. An analysis of this longitude effect (⁷) shows that Ellsworth is (54 ± 6) minutes late with respect to Mina Aguilar in the May storm commencement. Mt. Wellington turnes out to be $3^h 45^m \pm 10^m$ late.

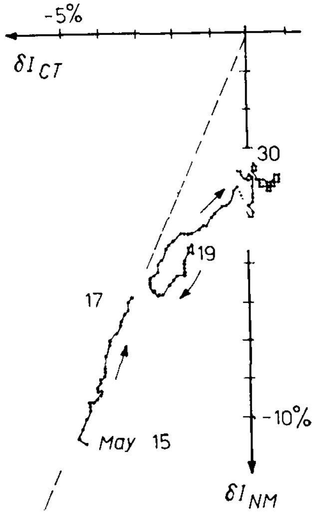

Fig. 7. – Item Fig. 5, for the neutron monitor *vs.* cubical telescope at Ellsworth. CT data for the 18th are not available. Again, a departure from the original line is clearly shown for the days following the 3-rd subinterval.

(⁷) J. G. Roederer, J. R. Manzano and O. R. Santochi: preprint C.N.E.A., in press.

3. – The increase on May 14.

Fig. 8 shows half-hourly data recorded at our different stations on the 14th of May. Percentage values are referred to the mean intensity at that day. The increase at Ellsworth is many times greater than at the other stations (including Mt. Wellington and others). It is of about 9% for N.M. and 2% for C.T. It starts at (0600 ± 0015) UT, both for N.M. and C.T. Intensity decays gradually until 1800 UT, when it reaches again a minimum (absolute minimum of the May storm). C.T. data are not available after 1600 UT. Violent fluctuations occur during the intensity decay in the nucleonic component; careful checks of equipment operation definitely rule out the possibility of attributing these fluctuations to equipment unstability.

Increases at Mina Aguilar and Ushuaía are of much smaller amplitude; the intensity rise is more gradual, except at Mina Aguilar, where a rather sudend jump is seen at 0330 UT. This is confirmed by 15 minute data. In principle, it would be hard to rule out entirely a contribution of daily variation, which is quite high during neighbouring days, the maximum occurring just around 1000 UT. However, a brief inspection of data from stations differing substantially in longitude from ours, still shows the existence of an increase occurring at nearly the same UT interval.

The magnitude of these increases, referred to a level represented by the extrapolation of the intensity curve of the 3-rd interval into the second subinterval (Fig. 1), is given by the following rough figures: Mina Aguilar 1.4%; Ushuaía 2.5%; Mt. Wellington 3.2%; Ellsworth 5.6% (mean over 5 hours). These values correspond to neutron monitors only. Excluding Ellwsorth, and taking Mina Aguilar as reference, we obtain from Fig. 4 a variation spectrum of $\gamma \simeq 0.9$. This value is similar to the exponent of the primary variation spec-

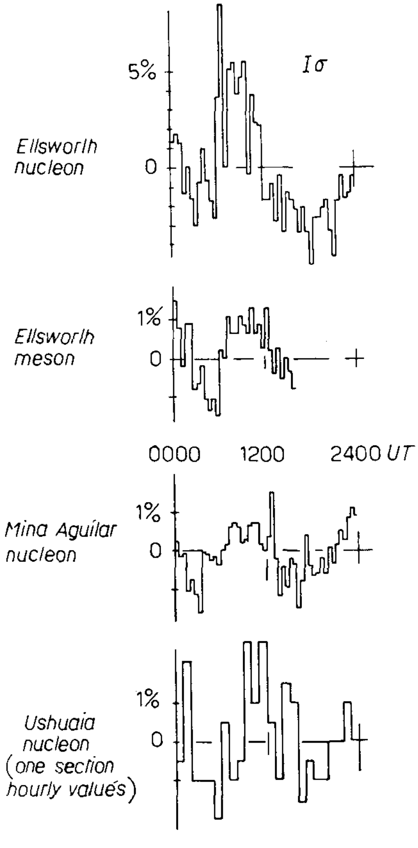

Fig. 8. – 30 min data for the 14th of May, showing the sudden increase with subsequent decay at Ellsworth, and the minor increases at Mina Aguilar and Ushuaia.

trum of the daily variation (8). The strong increase at Ellsworth might be interpreted as an additional enhancement of the primary low energy flux.

The most striking feature of these increases, particularly that detected at Ellsworth, is that there was no simultaneous solar event to which it might have been associated. No flare was reported (*), and geomagnetic activity was remarkably low at this day, compared to preceding and following days (**). If we nevertheless suppose that this additional flux at Ellsworth was of solar origin, and compute impact zones for a solar event which took place at about 0600 UT (9), we get the picture of Fig. 9. Some cosmic ray stations located in or near impact zones are shown.

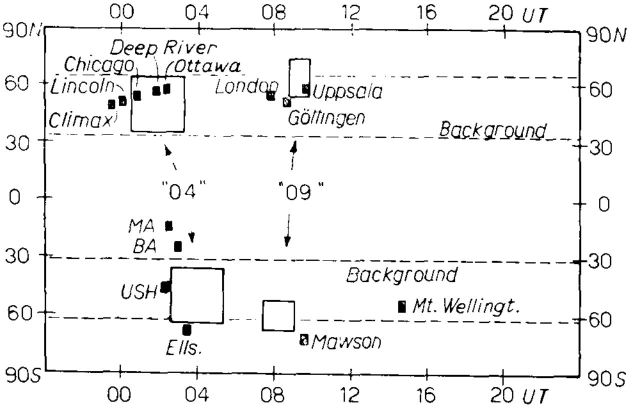

Fig. 9. – Impact zones for a solar event occuring at 0600 UT on May 14.

With respect to Ellsworth, we note that this station lies near the southern edge of the impact zone (drawn for a rigidity of 1 GV). These impact zones, however, are calculated using the centered dipole model, for which the geomagnetic cut-off at Ellsworth would be of about 0.4 GV only. Taking into account higher order corrections, as given in (6), the real situation must be different from that sketched in Fig. 9. The impact zones will be distorted by this multipole correction. In the particular case of the « 04 » impact zone in the southern hemisphere, it will be displaced several degrees southwards. There is therefore a great chance for Ellsworth of having been situated in the true impact zone during the increase on May 14. We look forward to analyse 15 minute data from other stations lying in or near the impact zones shown in Fig. 9.

(8) L. I. DORMAN: *Cosmic Ray Variations*, Translation, Technical Documents Liaison Office, Wright-Patterson Air Force Base, Ohio.

(*) *Note added in proof.* - In the meantime, a couple of flares of importance 1 and one of importance 2 were reported to us.

(**) This, however, may be of some significance.

(9) J. W. FIROR: *Phys. Rev.*, **94**, 1017 (1954).

4. – The magnetic storm of May 24.

Cosmic ray intensity behaviour during the 6-th subinterval (Fig. 1) is of greatest interest. In our stations Mina Aguilar, Buenos Aires and Ellsworth (Ushuaía cannot be taken into account in view of the high statistical fluctuations), a first, very small decrease occurs almost simultaneously with the magnetic storm commencement. Then, intensity rises again for some hours, falling back to a minimum towards midnight. This second decrease is much more pronounced than the first one, and coincides more or less with the decrease in the horizontal component. Considering the reduced amount of data from foreign stations available to us at present time, it is not clear to us whether this splitting up into two decreases is of world-wide character or not.

If we consider the second, bigger decrease as the « true » Forbush decrease, it shows an extremely strong longitude dependence: Ellsworth is about two hours in advance with respect to Mina Aguilar; Rome ([2]) leads 5 hours and Mt. Wellington as much as 12 hours.

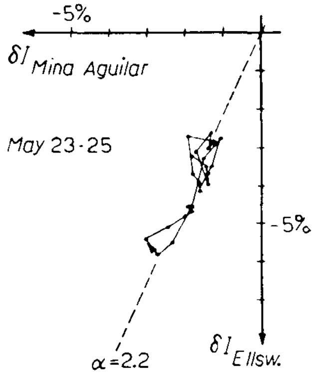

Fig. 10. – Percentage intensity variation diagram for the small Forbush decrease occuring on May 24, for neutron monitors at Ellsworth and Mina Aguilar.

This shift in time has to be taken into account in our ΔI vector diagrams. The result is shown in Fig. 10, for the pair of stations Ellsworth and Mina Aguilar; the latter having been delayed two hours with respect to the former. The slope is given by

$$\alpha_{\text{ELLS-MA}} = 2.3 \pm 0.2 \,,$$

which is more or less coincident with the (2.6 ± 0.2) slope corresponding to the general variation at that time (see Fig. 5). α values for other stations are

$$\alpha_{\text{USH-MA}} = 1.3 \pm 0.2 \,,$$
$$\alpha_{\text{MT WELL-MA}} = 1.5 \pm 0.2 \,.$$

These results, together with those of Sect. **2**, tell us that the primary variation spectrum acting after the 18th, did not change its form appreciably during the storm of May 24; it merely modulated its amplitude. We insist on the fact that it is not the original variation spectrum, responsible for the first stage of the big storm, which is left untouched by the May 24 storm. Rather, it is the modified spectrum, acting after the 18th, to which a similar variation spectrum is superposed on the 24th. In other words, the relative depression of low energy flux, present after the 18th (Sect. **2**) is not removed nor changed during the storm in the 6-th subinterval. The cosmic ray modulation mechanism for this storm must be the same, although independently acting, as that responsible for the general recovery during its final stage. This result, if confirmed to be of world-wide character, may be used as a check of different theories for modulation mechanisms which cause cosmic ray Forbush decreases.

Finally, as an alternative, we may advance the hypothesis that what we see during the 6-th interval, is a Forbush decrease starting more or less in coincidence with the sudden commencement of the magnetic storm (0540 UT), and to which an extra flux of primary particles is superposed. This extra flux causes an intensity increase, which lasts (8÷10) hours and which is strongly longitude-dependent. Once this flux vanishes, intensity falls back to the corresponding Forbush decrease level.

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We thank H. GHIELMETTI (E.F.I.N.S., Chicago) for valuable informations and Mrs. A. MANZANO and Miss L. LANFRANCO for collaboration in the calculations.

RIASSUNTO (*)

Si analizza l'intensità dei raggi cosmici durante la tempesta magnetica del Maggio 1959, usando i dati dei rivelatori di neutroni e dei telescopi cubici di Mina Aguilar, Buenos Aires, Ushuaia et Ellsworth (Antarctica). Lo spettro di variazione dei primari è stimato secondo un metodo delineato in uno scritto recente (¹). Si analizza dettagliatamente il comportamento dell'intensità durante la ripresa. Si ottengono i seguenti risultati. Lo spettro di variazione di primari, che agisce sino al 18 Maggio, ha una forma approssimata data da $\delta D/D = \delta k(t)\cdot E^{-0,5}$ valida sino ad altissime energie. Verso il 18 questo spettro cambia forma a basse energie (< 3.5 GeV), in modo simile a quanto accadde durante la ripresa dopo la tempesta del luglio 1959. Questo cambiamento può essere interpretato come una rimozione addizionale delle particelle di bassa energia, che si protrasse almeno sino alla fine del mese. Il 14 Maggio la variazione di intensità è spiccatamente peculiare, malgrado che questa fosse una giornata tranquilla dal punto di vista solare e geomagnetico. Si ha un decremento su scala mondiale, con un incremento sovrapposto, durato 10 ore, che è particolarmente alto ad Ellsworth (9% nel rivelatore di neutroni, 2% nel telescopio cubico). Si mostra che Ellsworth era collocato nella zona d'urto 04 per un evento solare simultaneo. Il 24 si ebbe un piccolo decremento Forbush su scala mondiale, associato ad una tempesta magnetica ed un decremento nella componente orizzontale del campo magnetico. Questo decremento di Forbush, che è spiccatamente dipendente dalla latitudine, corrisponde ad uno spettro di variazione dei primari che ha la stessa forma di quello cui è dovuta la ripresa generale in azione al momento, cioè, dopo il cambiamento nelle basse energie del 18.

(*) *Traduzione a cura della Redazione.*

3370

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